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# Efficient implicit simulation for incremental forming.

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Single Point Incremental Forming (SPIF) is a displacement controlled process performed on a CNC machine. A clamped blank is deformed by the movement of a small sized tool that follows a prescribed tool path. An extensive overview of the process has been given in [1]. The tool size plays a crucial role in the SPIF process. The small radius of the forming tool concentrates the strain at the zone of deformation in the sheet under the forming tool. The tool has to travel a lengthy forming path all over the blank to introduce the deformation. Numerically, this requires performing thousands of load increments on a relatively fine FE model resulting in enormous computing time. A typical computing time for implicit simulation of a small academic test is measured in by days. The focus of this paper is to efficiently use the implicit time integration method in order to reduce the required computing time for incremental forming implicit simulation drastically.

Because of the localised plastic deformation, parts of the FE mesh that are in the vicinity of the tool experience a strong nonlinearity. The strong nonlinearity is a combination of material and geometrical nonlinearities. The rest of the FE mesh that models the elastically deforming part of the blank experiences only a weak geometrical nonlinearity. It is required to use of the standard Newton method because of the strong nonlinearities in the set of equations but it is inefficiently used for the large elastically deforming part. Therefore, it becomes necessary to use different treatments that are accurate and computational efficient for different part of the FE mesh. The fully nonlinear treatment is used for the localised plastic deformation. The rest of the FE mesh that is elastically deforming is treated by a pseudo–linear approach. The pseudo–linear treatment applies a nonlinear geometrical and material update for the tangent stiffness matrix and the internal force vector only once every numbers of increments. Within the increment(s), the tangent stiffness matrix is reused, like the modified Newton method. The internal force vector is linearly updated by the multiplication of the tangent stiffness matrix and the incremental displacement vector.

The super element technology is used to implement the efficient implicit time integration procedure. A FE mesh is substructured into super elements. This re–cast the assembly procedure to be over all super elements instead of elements. It facilitates partitioning a FE mesh using different update frequencies: every iteration, increment and multi-increments. Also, it manages and organizes the update of the tangent stiffness matrix and the internal force vector. The implementation and testing is done in the in–house FE code DiekA.

The movement of the tool, consequently the localised forming zone, results in a new distribution of the strong and the weak nonlinear partitions and new sizes of the partitions. Therefore, indicators are developed for localised deformation. The indicators generically classify the super elements into different update frequency strategies (iterative, incremental or multi-incremental). The indicators are the current tool location, plastic deformation in the previous load increment and the shape change in the previous load increment. The tool indicator uses the strategy of a search radius to classify the super elements based on the distance between the super element and the tool surface into iterative, incremental and multi-incremental update strategies. The plastic deformation in the previous load increment is used in the plastic indicator in order to turn incrementally treated super elements into iterative treatment. The geometrical indicator that is based on shape change classifies multi-increments super elements into incremental treatment.

To compare the accuracy and efficiency of the efficient implicit approach to the standard Newton approach, a single point incremental forming process of a 45° pyramidal shape is simulated. The 20 mm deep pyramid is made out of a $100 \times 100 \times 1.2$ mm initially flat blank. An analytical spherical tool of 10 mm radius is used. The tool follows a counter clockwise tool path for 40 loops. In each loop, the tool moves 0.5 mm vertically downwards. At a fixed vertical position, the tool performs the in-plane tool path. the simulation finishes when the tool reaches the end of loop 40. The numerical blank is discretized with 6400 triangular shell elements. The material model is representative of mild steel and it is kept as simple as possible. The isotropic yield behavior of the material is modelled with the von Mises criterion. The work hardening is governed by the Swift relation: $\sigma = 500(\varepsilon + 0.00243)^{0.2}$ where $\sigma$ and $\varepsilon$ are the flow stress and the equivalent plastic strain, respectively.

The CPU time required by the simulations is listed in Table 1. The standard Newton simulation requires 55.27 hrs to finish 10822 load increments. The efficient implicit simulation solves almost the same number of load increments (less by 173 increments) in 14.63 hrs. The efficient implicit method successfully accelerates the standard Newton implicit simulation by a factor of 3.78. The speeding factor is defined as the ratio of Newton simulation CPU time to the efficient simulation CPU time. The results achieved by the efficient implicit method have a very good agreement with the results achieved by the Newton method e.g. the equivalent plastic strain is shown in Figure 1. The maximum achieved equivalent plastic strain by the Newton method is 0.969 while the efficient implicit method under estimates it by 1.75%. This verifies that the efficient implicit method can significantly accelerate the standard Newton method while maintaining the accuracy of the achieved results.

Table 1: The simulations performance

| | CPU time (hr) | Nr. increments | Speed factor |
|---|---|---|---|
| Newton | 55.27 | 10822 | 1.00 |
| Efficient | 14.63 | 10649 | 3.78 |

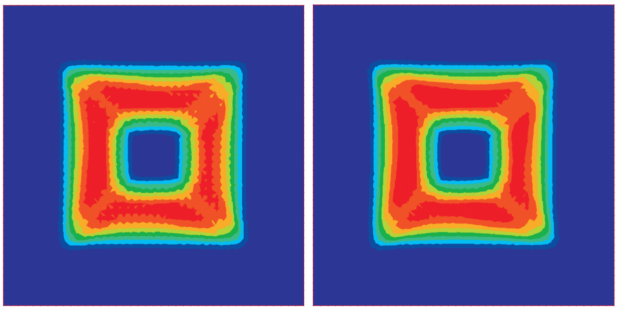

Figure 1: The achieved equivalent plastic strain by the Newton method (left) and the efficient implicit method (right).

## References

[1] J. Jeswiet, F. Micari, G. Hirt, A. Bramley, J. Duflou and J. Allwood, *Asymmetric single point incremental forming of sheetmetal*, Annals of the CIRP, vol. 54:2,pp. 88−114, 2005.